LOOKING FOR EXTRA-DIMENSIONS AT THE WEAK SCALE: EXPERIMENTAL SEARCH FOR KALUZA-KLEIN STATES SIGNATURES AT THE e^+e^- LINEAR COLLIDER [a]

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An experimental search for signatures of Kaluza-Klein graviton states at the 500 GeV e^+e^- linear collider, in which the graviton states are produced in association with a photon, is presented. The study of the signal extraction is performed with the help of Monte Carlo simulations.

1 Introduction and motivations

Quantum gravity is presently best described within the framework of superstring theories. Superstring [1], allowing to unify gravity with the interactions described in the standard model and to remove divergences from quantum gravity, are known to live in 10 space-time dimensions. Furthermore, superstring dualities [2] have tought us that the superstring scale may not be tied to the Planck scale but becomes a rather arbitrary parameter [3] which as been proposed to be possibly as small as the TeV scale [4]. This observation already opens formally the possibility of the existence of more than 4 space-time dimensions at the weak scale.

The proposal that the standard model particles and interactions leave in the usual 4 dimensional space-time while gravity propagates in a higher-dimensional space [5] leads to a solution of the hierachy problem. In this framework, quantum gravity is characterized by a fundamental scale M of order $\sim$ TeV and gravity propagates in a space with δ extra-dimensions of size R. The Newtonian gravitationnal constant G_N is then expressed as $G_N^{-1} = M_P^2 = 8\pi R^\delta M^{2+\delta}$ where M_P is the Planck mass so that M can be seen as the effective Planck mass of the higher dimensional theory. Such a picture of a standard model confined to a lower dimensional space and gravity propagating in the bulk is naturally imbedded within superstring theories [6]. Furthermore, grand unification through extra-dimensions has been shown to be possible at scales as low as scales close to the weak scale [7].

These observations lead to a wide spectrum of phenomenological consequences for conventional Newtonian gravitation, particles physics, astrophysics and cosmology [8]. In the higher i.e. 3+ δ, dimensional space, the graviton propagates as a massless, spin-2 particle. Projected onto the normal 3 dimensional space, where the standard model leaves, it appears as a tower of massive Kaluza-Klein excitations.

In this study, we focus on the production of a Kaluza-Klein (KK) graviton in association with a photon at e^+e^- colliders, as suggested [5] for a possible experimental test, and more specifically at the linear collider at $\sqrt{s} = 500$ GeV. Note that in the early '90, a proposal for a search for new dimensions at a TeV has been made [9].

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2 Cross-Sections, Signature and backgrounds

The cross-section for the process $e^+e^- \rightarrow \gamma$ graviton has been calculated [10] (see also [8]), without the inclusion of initial state radiation (ISR) of photons, and yields to:

$$\frac{d\sigma}{dx_\gamma d\cos\theta}(s) = \frac{\alpha}{64}\frac{2\pi^{\frac{\delta}{2}}}{\Gamma(\frac{\delta}{2})}(\frac{\sqrt{s}}{M})^{\delta+2}\frac{1}{s}f(x_\gamma,\cos\theta) \tag{1}$$

with $x_\gamma = \frac{2E_\gamma}{\sqrt{s}}$. The angle θ is the angle between the photon and the beam direction. In equation 1, $f(x,y)$ is defined by:

$$f(x,y) = \frac{2(1-x)^{\frac{\delta}{2}-1}}{x(1-y^2)} \times [(2-x)^2(1-x+x^2) - 3y^2x^2(1-x) - y^4x^4] \tag{2}$$

The cross-section 1 has divergences for for $x_\gamma \rightarrow 0$ and $\cos^2\theta \rightarrow 1$ which means that the photon will be close to the beam with an energy spectrum favouring very small energies with respect to the beam energy.

In this work, the effect of ISR is included by introducing an energy-dependent e^+e^- luminosity function which can read [11]:

$$L_{ee}(z) = [\beta(1-z)^{\beta-1}(1+\frac{3}{4}\beta) - \frac{1}{2}(1+z)] \times [1+\alpha_{em}(\frac{\pi}{3}-\frac{1}{2\pi})] \tag{3}$$

where:

$$\beta = \frac{2\alpha_{em}}{\pi}(\ln\frac{s}{m_e} - 1) \tag{4}$$

In terms of this function, the total cross-section is then given by:

$$\sigma(s) = \int_0^1 dz L_{ee}(z)\sigma(zs) \tag{5}$$

Figure 1 (left part) shows the total cross-sections in the domain $E_\gamma > 5$ GeV and $1^o < \theta < 179^o$, with and without the inclusion of the ISR, as a function of the scale in TeV for various value of δ and this at $\sqrt{s} = 500$ GeV. Including the ISR leads to a lowering of the total cross-sections by an amount which can be of the order of 10 % or even more, depending on the domain in E_γ and θ considered.
These cross-sections ranges from 10^{-2} pb up to several picobarns.

As the KK graviton G interacts very weakly with matter and has a very long lifetime, G can be considered as a non-interacting stable particle. In consequence, the signature for the process $e^+e^- \rightarrow \gamma G$ is characterized by the presence of a photon and missing energy (and, eventually, a photon from ISR).

3 Signal extraction

The main physical backgrounds from processes of the standard model for the above signatures come from $\nu\bar{\nu}\gamma(\gamma_{ISR})$ production as well as, more marginally, from $Z\gamma$ and $ZZ(\gamma_{ISR})$ productions where the Z boson decays into neutrinos. Including effects from the detector, such as unefficient measurements or loss of particles, other backgrounds may become relevant. This may be the case for Bhabha processes

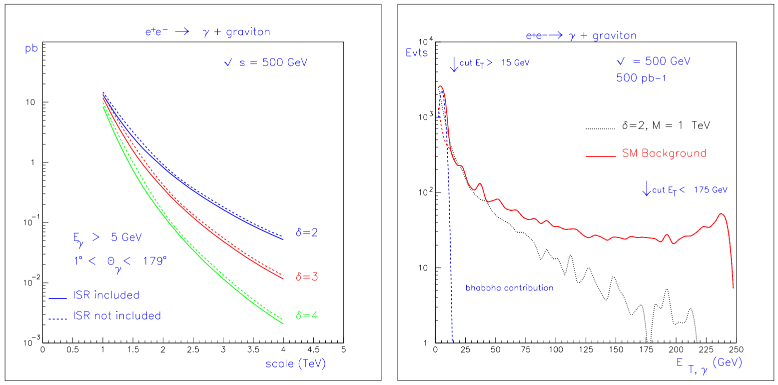

Figure 1: Left: total cross-section in picobarns. Right: transverse energy distribution of the candidate photon.

with an ISR photon or $\gamma\gamma(\gamma_{ISR})$ productions as well as $WW(\gamma_{ISR})$, $We\nu(\gamma_{ISR})$, $Zee(\gamma_{ISR})$ productions. In order to study the extraction of a KK graviton signal from these backgrounds at a typical detector at the linear collider, we perform a Monte-Carlo study in which the $\nu\bar{\nu}\gamma(\gamma_{ISR})$ events are generated by the NUNUGPV package [12] and the Bhabha events are generated by the BHWIDE package [13]. At $\sqrt{s} = 500 GeV$, the total cross-section for $\nu\bar{\nu}\gamma(\gamma_{ISR})$ is found to be equal to 9.72 pb with an uncertainty of the order of 20 % and the total cross-section for Bhabhas is found to be 14.7 nb. The events corresponding to all the other processes quoted above are generated with the help of the PYTHIA 5.7 package [14] with the following cross-section at $\sqrt{s} = 500$ GeV , 8.2 pb $(Z\gamma)$, 0.55 pb (ZZ), 8.0 pb $(\gamma\gamma)$, 7.7 pb (WW), 5.3 pb $(We\nu)$ and 7.4 pb (Zee), all with ISR γ's.

We have developped an event generator for the production of a KK graviton in association with a photon which includes the effect of ISR according to the above formulae.

All the generated events are then passed through a fast simulation package of a typical detector at the linear collider i.e. the SIMDET package [15] in its version 3.1.

The most important parameters for this detectors concern the electromagnetic calorimeter and the instrumented mask. They have been tuned (but not yet optimised) such that, for the electromagnetic calorimeter, the minimum deposited energy is 0.1 GeV, the electron misinterpretation probability is 0.01, the angular acceptance is 4.5^o-175.5^o and the energy resolution is 10 %. As for the instrumented mask, we have an angular coverage from the electromagnetic calorimeter i.e. 4.5^o down to 1^o, with a minimum deposited energy of 10 GeV.

The events are selected by taking the information from the so called BEST record of SIMDET 3.1 which gives the best estimate for the energy and direction of an object. A candidate photon is defined as a detected object having zero charge and zero mass. The selection then proceeds by requiring the presence of only one candidate photon in the event. Figure 1 (right part) shows the distribution of the transverse energy of this candidate photon for all the above backgrounds, assuming an integrated luminosity of 500 pb^{-1} at $\sqrt{s} = 500$ GeV. A signal for 2 extra-

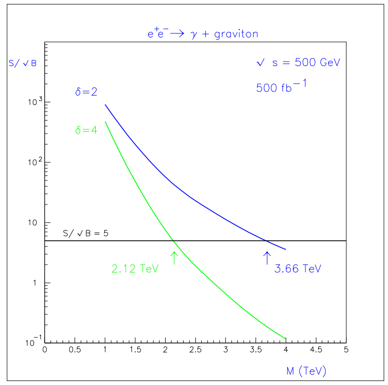

Figure 2: The $S/\sqrt{B}$ ratio.

dimensions at a scale of 1 TeV is also shown. The particular contribution of the Bhabha background is singled out and shown to concern the part below 15 GeV of the transverse energy distribution of the candidate photon.

Requiring the transverse energy of the candidate photon to be greater than 15 GeV, in order to suppress the Bhabha background, and lower than 175 GeV, in order to reduce the main background from $\nu\bar{\nu}\gamma(\gamma_{ISR})$, allows to extract the signal from KK graviton which will then appear as an excess of events having a single photon and missing energy events.

Figure 2 shows the $S/\sqrt{B}$ ratio, where S stands for signals and B for total background, as a function of the scale M extrapolated to an integrated luminosity of $500 fb^{-1}$. Requiring the $S/\sqrt{B}$ ratio to be greater than 5 allows a reach in terms of M of the order of 3.66 TeV for 2 extra-dimensions and 2.12 TeV for 4 extra-dimensions.

One can try to lower the 15 GeV cut on the transverse energy of the candidate photon down to 10 GeV or even 5 GeV. This allows to increase the reach in terms of M up to values of the order of 4 TeV for 2 extra-dimensions but the price is a precise control of the background coming from the low energy part of the photon spectrum.

4 Conclusions and perspectives

At the e^+e^- linear collider, the search for $e^+e^- \to \gamma$ graviton seems a promising way to look for extra-dimensions at the TeV scale. Although the inclusion of the effect of ISR lowers the total cross-sections, the present Monte-Carlo study, including a fast detector simulation, shows that this signal can be extracted from the physical and instrumental backgrounds and the exploration of the $M = 3.5$ TeV - 4 TeV mass scale domain for 2 extra-dimensions at $\sqrt{s} = 500$ GeV at 500 pb^{-1} is feasible. A very good photon measurement and identification as close to the beams as possible and a good hermiticity are among crucial requirements on the detector at the e^+e^- linear collider for such a measurement. The study of the beam polarization will be done in a future work and we foresee an increase of reach in terms M as anticipated

in [8] and [10]. Complementary processes such as $e^+e^- \to Z$ graviton with a Z boson decaying into two fermions may help in detecting/confirming the effect of extra-dimensions at the weak scale at the linear collider. Last but not least, processes such as $e^+e^- \to \gamma$ dilaton (or even $e^+e^- \to (\gamma_{ISR})$ dilaton dilaton processes), leading also to signature with a single photon and missing energy, may help in revealing the stringy nature of quantum gravity. Fascinatingly enough, Kaluza-Klein dilaton production can be distinguished from Kaluza-Klein graviton production since the angular spectrum of the single photon which can be detected may show competely different features [16]. Work in this direction is also underway.

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